Simulation of prompt photon production in Sherpa

Photon Physics at Hadron Colliders
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Based on

- arXiv:0912.3501 (Stefan Höche, Steffen Schumann, FS)
- arXiv:0903.1219 (Stefan Höche, Frank Krauss, Steffen Schumann, FS)

ME+PS merging in a nutshell

- Parton shower approximates corrections from higher-order real emission MEs
- Approximations only valid for collinear emissions
  $\Rightarrow$ Want to improve wide-angle emissions using the exact real emission MEs
- Avoid double counting and preserve shower evolution: ME+PS merging a la CKKW Catani, Krauss, Kuhn, Webber (2001); Höche, Krauss, Schumann, FS (2009)
- Note: Only LO accuracy in the inclusive process (as opposed to e.g. *Phox, ...)

QCD ME+PS merging

- Include higher-order QCD MEs to correct QCD shower
- Example: $\gamma\gamma$, $\gamma\gamma$ + jet, $\gamma\gamma$ + 2 jets
- Parton shower only "unfolds" PDF
- Higher-order MEs contain unordered contributions in PS evolution view:
  "γ jet + γ", "2 jets + $\gamma\gamma$"

$\Rightarrow$ "Fragmentation" component included

QED ME+PS merging

- Include higher-order QED MEs to correct QED shower
- Example: jet jet, jet jet + γ, jet jet + $\gamma\gamma$
- MEs will be regularised by some isolation criterion, and shower takes over below
- (Can be combined with QCD ME+PS to interleaved QCD$\oplus$QED ME+PS)

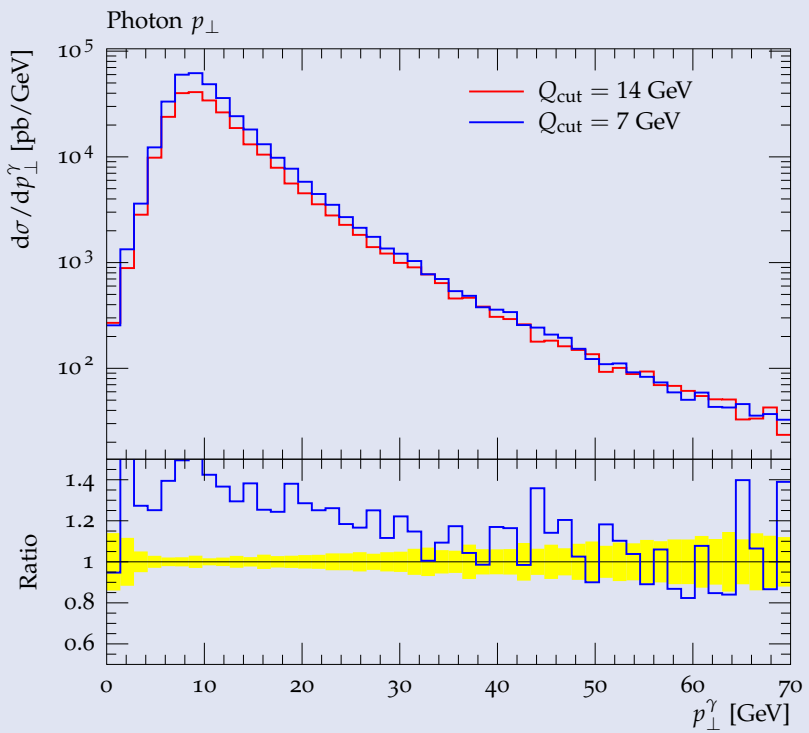
$\Rightarrow$ Sample inclusive wrt photon isolation

How it works practically

- Use $\sim$ analysis photon isolation definition (but slightly looser) as inclusive parton-level cut, set ME+PS separation Q_{cut} low enough (cf. below)

$\Rightarrow$ Inclusive sample for isolated photons,
including non-perturbative effects (hadronisation, MPI, ...)

ME+PS separation criterion Q_{cut}



Example: γ+jets at LHC

- Generated with fixed photon $p_\perp$ cut of 7 GeV
- Two different Q_{cut}: 7 GeV vs. 14 GeV
- Problem: Why is the $p_\perp$ spectrum biased up to such high photon $p_\perp \approx 50$ GeV?

Diagnosis

- γ+jet implies a factorisation scale like $\mu_F \sim p_\perp^\gamma$
- Parton shower does not allow for QCD emissions above μ_F ($\rightarrow$ factorisation)
- As opposed to other processes like Z+jets we can now have very low μ_F
  - $\Rightarrow$ Emission rate from PS alone (and thus factorised cross section) much too low
  - $\Rightarrow$ ME+PS corrects for this, but only down to Q_{cut}

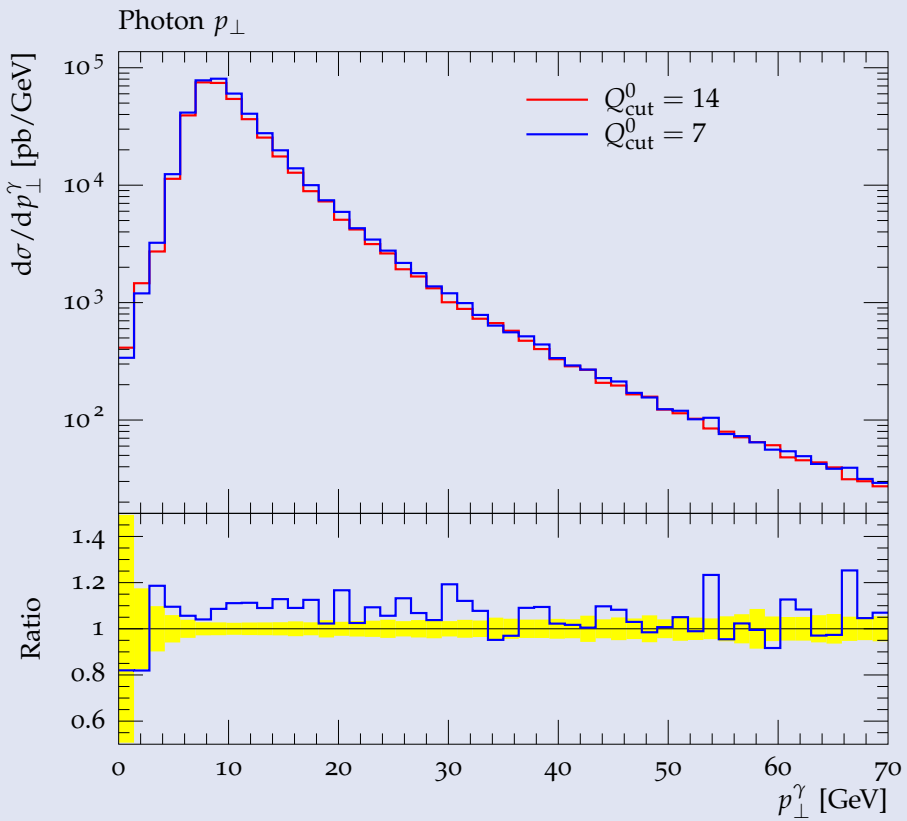
$\Rightarrow$ We might still be missing rate for the cases where "$\mu_F < Q_{\text{cut}}$"

Solution

- Choose a dynamical Q_{cut} depending on the μ_F of the event (similar to DIS simulation arXiv:0912.3715)
- Example: $\left(\frac{Q_{\text{cut}}}{E_{\text{CMS}}}\right)^2 = \frac{\left(\frac{Q^0_{\text{cut}}}{E_{\text{CMS}}}\right)^2}{1.0 + \left(\frac{Q^0_{\text{cut}}}{\kappa p_\perp^\gamma}\right)^2}$

  where Q^0_{cut} is $\sim$ the fixed value of Q_{cut} one would have chosen before and κ can optionally be chosen < 1 as a safety factor, e.g. $\kappa = 0.6$
- (Note: This is not a "randomly smeared out" Q_{cut} which has sometimes been suggested to get rid of kinks, but a well-defined Q_{cut} at each phase space point)

With dynamical Q_{cut}

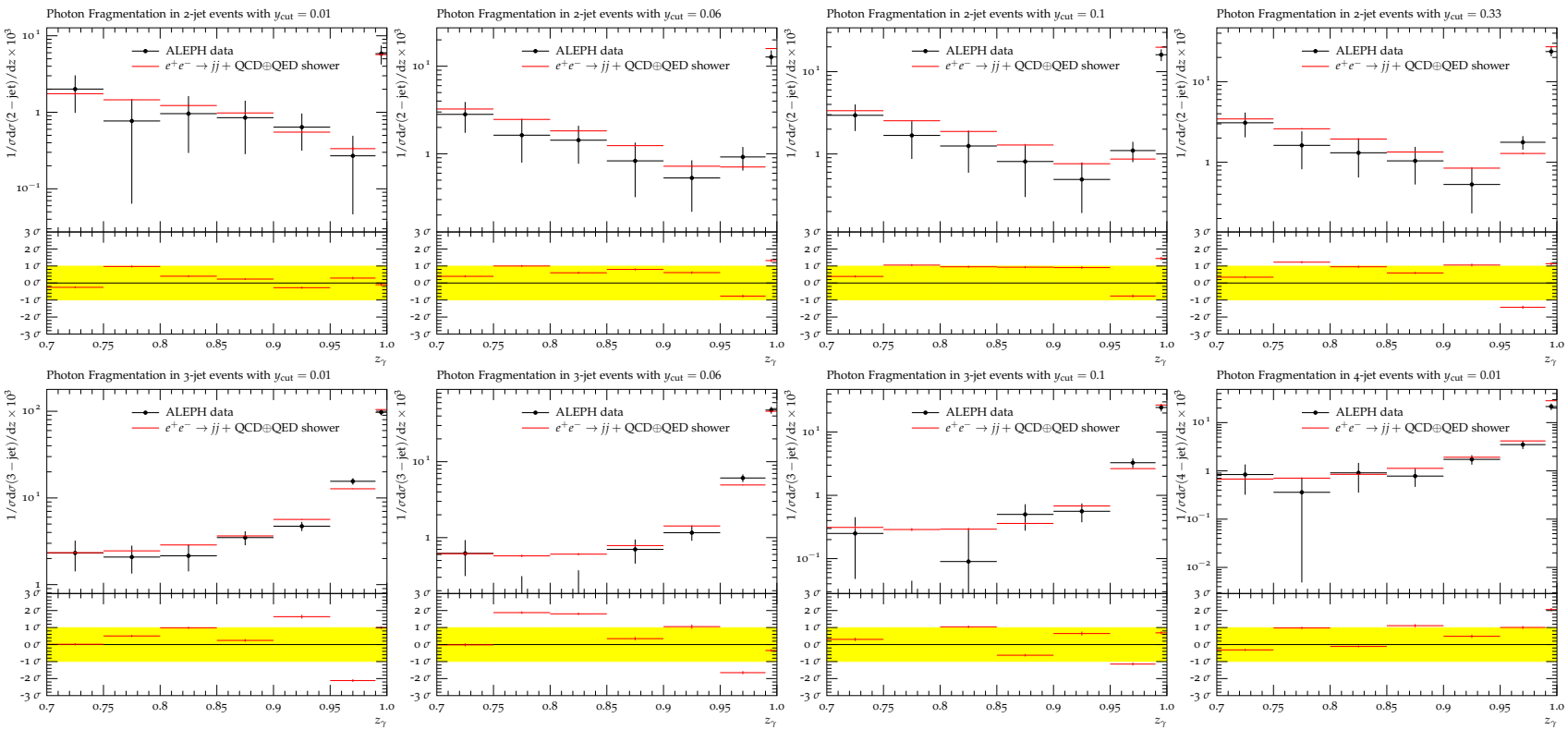


- Generated with fixed photon $p_\perp$ cut of 7 GeV
- Two different Q_{cut}^0: 7 GeV vs. 14 GeV

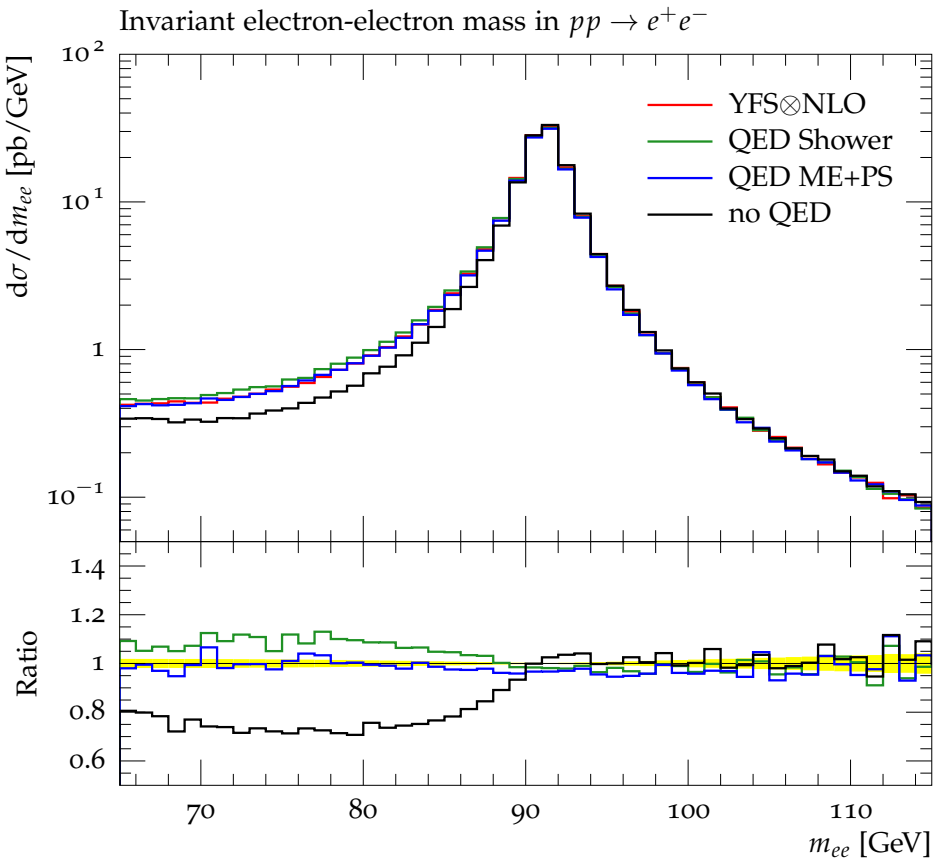
$\Rightarrow$ Basically no bias anymore

Fragmentation function

- Basis: An interleaved QCD+QED parton shower generates the perturbative part of the photon fragmentation function $D_\gamma(z_\gamma, \mu)$
- Comparison to ALEPH data for validation
  - Measurement suggested by Glover, Morgan (1994), done by ALEPH (1996)
  - "Democratic" approach: Cluster all particles, find γ in jets with $z_\gamma > 0.7$
  - Vary the jet resolution measure y_{cut} as scale μ
  - Monte-Carlo setup: $e^+e^- \to jj$ + QCD⊕QED parton shower



Example: QED ME+PS for radiation from leptons



Marek Schönherr, PhD thesis (2011)

- Improve QED shower by including tree-level ME corrections
- Example:
  - $pp \to e^+e^-$
  - $pp \to e^+e^-\gamma$
  - $pp \to e^+e^-\gamma\gamma$
  - …
- Here compared for invariant mass of "dressed" leptons
  - YFS soft-photon resummation including NLO correction
  - pure QED shower
  - QED ME+PS
  - no QED radiation

Basic idea

"Democratic" extension of QCD ME+PS merging to QED

- Take into account MEs with all combinations of partons and photons
- Regularise them by some kind of isolation criterion (may be different for QCD/QED)
- Fill in the region below the isolation with interleaved QCD⊕QED shower

⇓

Fragmentation component split into photon production through "ME" and "PS"

Practical difficulties

- Generating "photon production in PS" component is expensive
  (e.g. high dijet cross section, but hardly any events with hard/isolated photon)
- Sample is not inclusive if that contribution is left out
- Adjusting the separation criterion for each analysis would allow to leave it out
  But: Then conceptually identical to QCD ME+PS with photon isolation cuts

Example: QCD⊕QED ME+PS in diphoton production